

AN INVESTIGATION OF 46-YEAR-OLD BRIDGE DECK SLABS IN SNOWY COLD REGION

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Abstract

For proper maintenance of highway bridge slabs in snowy cold regions, it is necessary to establish a survey method for evaluating the remaining life of road structures and repair methods taking the characteristics of damage from freeze-thaw and fatigue into consideration. To obtain fundamental data for deterioration and damage to RC slabs in snowy cold regions, this study conducted various surveys and tests on the waterproofing layers and the cross-section of RC slabs that has been in service for 46 years in Hokkaido, Japan.

Introduction

It has been generally known that the damage to RC slabs of highway bridges, which are subjected to direct wheel loading, is principally caused by fatigue from wheel load running repetition. In snowy cold regions, on the other hands, there have been several cases of deterioration and partial collapse of RC slabs, even though the bridges are located under comparative lighter traffic volume than urban areas. Such damages are attributed to freezing-thawing action caused by environmental conditions in combination with fatigue action. A previous research showed that such combined damage is found throughout Hokkaido, irrespective of the grade of road (Mitamura et al. 2009). Also, the research experimentally found that fatigue durability of RC slabs is drastically reduced when the cover concrete is reduced by even 1cm in thickness, because the effective slab thickness is reduced.

In Japan, huge amount of bridges were constructed in high economic growth period from the late 1950s to the early 1970s. Efficient and effective maintenance system should be developed, because damage from freezing-thawing and fatigue are predicted to occur on these around 50-years-old bridges in the near future. To achieve that, it is necessary to establish a survey method for evaluating the remaining life of road structures and repair methods for proper maintenance that take the characteristics of damage from freezing-thawing and fatigue into consideration. For the one examination, authors conducted a field survey on the RC slab partially collapsed in September 2012 (Figure 1) to obtain fundamental data for establishing a comprehensive and systematic maintenance

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method. This paper reports on part of the results of surveys on deterioration of the waterproofing layers and slab concrete.

Outline of the surveyed bridge

The surveyed bridge was constructed in 1965 based on *Specifications For Highway Bridges* revised in 1956 (Japan Road Association 1956) and had been in service for 46 years before collapsed.

Table 1 lists the installation conditions and the structural characteristics of the surveyed bridge. It is located in central Hokkaido with an annual minimum temperature of -22.5°C on average from 1976 to 2012. The superstructure is composed of 3-span simple and no-composite girders. The daily heavy traffic volume is about 800 vehicles in two directions, which is comparatively lower than urban areas.

Figure 2 shows the plan and the cross-section of the bridge. In 1987, two stringers were added between girders G3 and G4 and between girders G4 and G5 intending to decrease in bending moment because the deterioration of the slab has progressed. At the same time, steel strip plates were attached to the bottom surface of the slab along longitudinal direction to make up for the deficiency of distribution reinforcing bars. Then, in 1989, a sidewalk was attached to the existing slab. Furthermore, in 2007, the waterproofing layers were installed to the whole slab surface together with the partial repairing of deterioration in upper slab concrete.

Survey method

This paper reports the results of two surveys on the damage conditions of the waterproofing layers and the RC slab. Both a visual survey and a tensile adhesion test were done for the former, and the cross-section of the slab was visually observed for the latter.

(1) Visual survey on the waterproofing layers

After the asphalt pavement was removed, the condition of the waterproofing layers and the drainage devices were visually surveyed. The waterproofing layers were installed on the carriageway of the bridge in 2007. A sprayed-type urethane waterproofing layer was applied to 50cm width from the edge of wheel guard and the boundary between the carriageway and the sidewalk. A heat-adhered asphalt waterproofing layer was used for the rest of the slab.

(2) Tensile adhesion test of the waterproofing layers

To check the reciprocal adhesion performance of the waterproofing layer, concrete and pavement, cores including the pavement, the waterproofing layer and the slab concrete

were sampled for the tensile adhesion test. The diameter of the core was 100mm and 46 cores were collected from the locations shown in Figure 3. The locations of core sampling were determined based on a systematic rule in Table 2. The test was conducted in the laboratory at a constant temperature of 23°C subjected to *Manual for Waterproofing of Highway Bridge Slabs* (Japan Road Association 2007).

(3) Observation of the cross-section

To check the damage condition of the slab, the cut cross-section of the slab was visually observed after it had been removed from the bridge. A 4-m-long slab portion taken from the section between girder G4 and the stringer (ST) was cut toward longitudinal direction (Figure 3). In selecting the cutting location, a part including both healthy parts and damaged parts of slab concrete was chosen based on damage condition to the pavement, traces of pavement repair and the condition of cracks and efflorescence on the bottom surface of the slab.

Results of the survey

(1) Visual survey on the waterproofing layers

An example of the condition of the waterproofing layers is shown in Figure 4. Figure 4(a) shows the area around the wheel guard and the expansion joint. In this case, the pavement, the adhesion sheet between the pavement and the waterproofing layer, the urethane waterproofing layer and the concrete were totally detached, and water infiltration was found in the upper part of the slab. Also, sand with 1cm thick was accumulated between the pavement and the adhesion sheet around the catch basin, which was about 2m distance from the expansion joint. It is thought that the detachment of the adhesion sheet has allowed water to intrude into the slab for a long time.

Figure 4(b) shows the condition near the boundary between the carriageway and the sidewalk. Around the photographed area, the waterproofing layer around the catch basin had lost adherence and was detached. Furthermore, a gap presence between the waterproofing layer and the surface of the curb allowed water to infiltrate under the waterproofing layer, although the waterproofing layer was raised onto the curb. The gap especially presented at curbstones joints.

Figure 5(a) shows a schematic of the water intrusion route near the boundary between the carriageway and the sidewalk. In addition to the gap between the raised part of the waterproofing layer on the curb and the curb surface, it is possible that water intruded through the boundary between the curb and the sidewalk and through the boundary between the wheel guard and the sidewalk. To prevent water intrusion there, it is necessary to extend the waterproofing layer onto the sidewalk with edge treatment as shown in Figure 5(b), instead of just being raised to part of the height of the curb stone.

(2) Tensile adhesion strength of the waterproofing layers

Figure 6 shows the distribution of tensile adhesion strength measured along the transverse line (T1-T9). In *Manual for Waterproofing of Highway Bridge Slabs*, 0.6N/mm^2 is specified as minimum tensile adhesion strength at a temperature of 23°C . Also, Table 3 lists the summary of tensile adhesion test results. Among the 46 test locations, 76% were below the standard value and 46% had zero tensile adhesion strength. Focusing on the tensile adhesion strength values along the transverse measurement lines (L2-L5), the values near the wheel guard and that near the catch basin (L5) are zero, meaning waterproofing was not maintained around these areas. Because the partial collapse of the slab occurred near the wheel guard, it is thought that the collapse was significantly affected by water intrusion from the side of the wheel guard. The area near the wheel guard is a part that the waterproofing layer must function properly, because water tends to gather at this area, and precise construction management has to be done for the installation of waterproofing layers. For the wheel load running line, tensile adhesion strength of less than the standard value reached 56% on the wheel load running line (L4), 64% on the center line (L3) and 70% on the area between the wheel load running lines (L2). As shown in Figure 6, the tensile adhesion strength tends to be moderately high along the wheel load running lines. This is probably caused by the increase in adhesion strength due to the roll-compacting of pavement by the wheel load running repetition.

Figure 7 is a contour map indicating the tensile adhesion strength distribution in the bridge. In this Figure, the warm colors indicate areas with a standard value of 0.6N/mm^2 or greater and the cold colors indicate values lower than the standard value. The areas with values greater than the standard value are distributed locally, mainly on the A-1 side of the 1st span, P-1 and P-2 of the 2nd span and the mid-span of the 3rd span. The areas near the wheel guard on the P-2 side of the 2nd span, where the partial collapse of the slab occurred, are colored in the range of tensile adhesion strengths lower than the standard value, including zero.

The performance of the waterproofing layers is influenced by several factors such as the surface treatment of slab concrete and air temperature at the time of layer installation (Sawamatsu et al. 2012a), and wheel load running in service. Furthermore, it has been experimentally demonstrated that repeated freezing-thawing decreases the adhesion strength of the waterproofing layers in snowy cold regions (Sawamatsu et al. 2012b). In future studies, factors that decrease the waterproofing performance will be analyzed in detail.

(3) Observation of the cross-section

Figure 8 shows an example of the cross-section of the slab. In the whole view of the cross-section (Figure 8(a)), the concrete on the right side of the cut slab is sound without cracks. However, the concrete on the left side of Figure 8(a) shows damage. The closer to

the expansion joint (P-2), the more damage is observed, and the surface concrete on the left side area is gravelized, i.e. aggregate and mortar are separated from concrete and this damage is called “gravelization” in the following. Figure 8(b)-(d) are enlargements of parts A, B and C in Figure 8(a). In part C (Figure 8(d)), horizontal cracks dividing the concrete into exfoliation layers can be observed, this paper calls this phenomenon “laminar exfoliation”. The number of laminar exfoliation layers is greater in the area closer to part B, and numerous laminar exfoliation layers are found throughout the cover concrete, as shown in Figure 8(c). The interval of each layer of exfoliation corresponds to the almost maximum size of coarse aggregate. Also, in part A (Figure 8(b)), concrete in the 5cm depth from the top surface is gravelized in addition to laminar exfoliation reaching down to lower reinforcing bars.

From the observation of the deterioration in each part, the deterioration shown in Figure 8 are thought to have started from the left side of the figure (Figure 8(a)) toward the right side. Here, the expansion joint is farther to the left of the left side of the figure where the deterioration and damage originated, and vehicles travel from left to right in the photographed section. Namely, deterioration and damage around the expansion joint were exactly caused by impact loading of the wheels with accelerating factors: rainwater and snowmelt water which tend to collect in this area. To secure the long-term durability of RC slabs, the importance of the waterproofing layers, which prevent water intrusion in slabs, is emphasized once again.

Based on the result of the cross-section observation, it is estimated that deterioration and damage to this RC slab had progressed through the stages shown in Figure 9. In sound stage, damage has not occurred in the slab, even though the slab has experienced repeated freezing-thawing and wheel load running. In occurrence of laminar exfoliation stage, laminar exfoliation occurs in the upper part of the slab, mainly in the cover concrete. In the progress and increase in laminar exfoliation stage, laminar exfoliation progresses toward horizontal direction. At the same time, new laminar exfoliation starts to occur in areas including the part below the upper reinforcing bars. However, laminar exfoliation stops increasing toward depth direction when the thickness of each layer approximately reaches the maximum size of coarse aggregate. In the gravelization stage, the aggregate and mortar in the sliced concrete layers separate in the surface of the slab concrete after the laminar exfoliation saturating exfoliation in depth direction. It is thought that the effective slab thickness decreases at this stage, as stated above, and that the fatigue durability is remarkably reduced.

The objective of this paper is to obtain data on deterioration and damage to an RC slab of a highway bridge that had been in service for 46 years in a snowy cold region, and the mechanism of laminar exfoliation occurrence was not clarified. Then, it is also necessary to clarify the relationship between laminar exfoliation and load-carrying capacity of the slab and fatigue durability and the process of deterioration and damage. Laminar exfoliation is thought to occur as a preliminary step toward gravelization, which

then triggers a marked reduction of fatigue durability. To evaluate the structural soundness of RC slabs in service, therefore, it is thought to be important to establish a method for surveying laminar exfoliation and the progress of damage.

Summary

(1) Deterioration and damage to the waterproofing layer

The tensile adhesion strength was 0 at 100% of the locations near the wheel guard and the catch basins. When installing the waterproofing layers near the wheel guard, it is necessary to complete the work carefully, because water tends to accumulate there. Also, the gap between the curb of sidewalk and the waterproofing layer, serving a route for water intrusion, indicates that it is necessary to extend the waterproofing layers to the wheel guard.

(2) Condition of deterioration and damage to the RC slab

From the cross-section of the RC slab, not only gravelized concrete in the upper part of slab concrete but also many horizontal cracks were observed. The deterioration and damage to the RC slab are estimated to have progressed from occurrence of laminar exfoliation to progress and increase in laminar exfoliation to gravelization of the cover concrete.

In future studies, the factors contributing to deterioration and damage will be examined by tests on slab concrete materials, and the occurrence mechanism of laminar exfoliation will be clarified. The relationship between laminar exfoliation and fatigue durability will also be examined.

References

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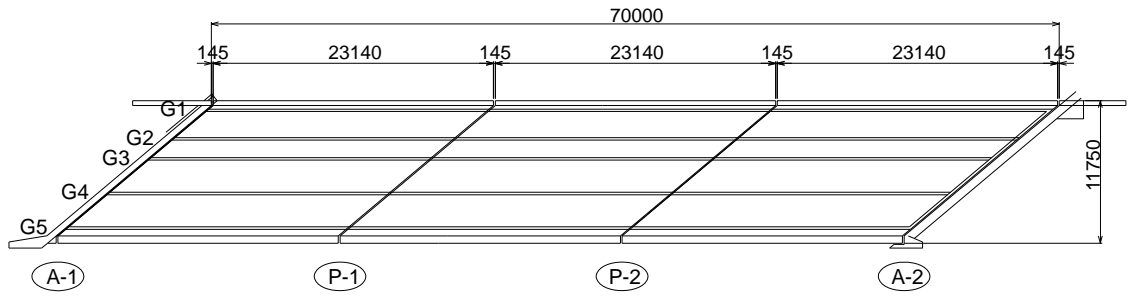
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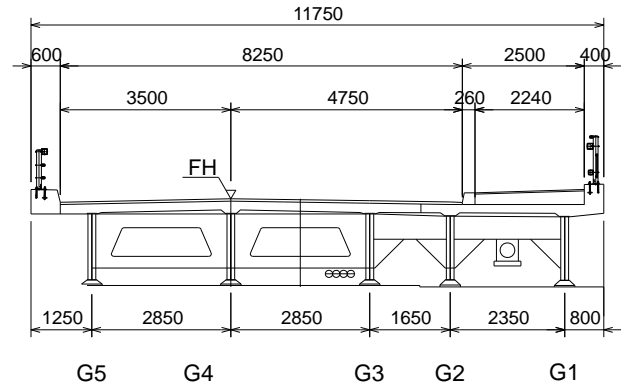
Figure 1 PARTIAL COLLAPSE OF RC SLAB IN HOKKAIDO: (a) damage condition on top surface; (b) view from bottom surface

Table 1 INSTALLATION CONDITIONS AND STRUCTURAL CHARACTERISTICS OF SURVEYED BRIDGE

Location	Central Hokkaido, Japan
Heave traffic volume	about 800 vehicles/day/2-directions
Minimum temperature	-22.5°C (average from 1976 to 2012)
Superstructures	3-span simple and no-composite girder Length : 22.50m x 3-spans Width : 8.25m (carriageway) + 2.5m (sidewalk)
Constructed year	1965
Design specification	<i>Specifications For Highway Bridges</i> (revised in 1956)
Slab thickness	180mm
Maintenance history	1987 : addition of stringers and attaching of bottom steel strip plates 1989 : widening of sidewalk 2007 : partial repair of upper slab concrete and installation of waterproofing layer



(a)



(b)

Figure 2 DIMENSIONS OF SURVEYED BRIDGE: (a) plan; (b) cross-section

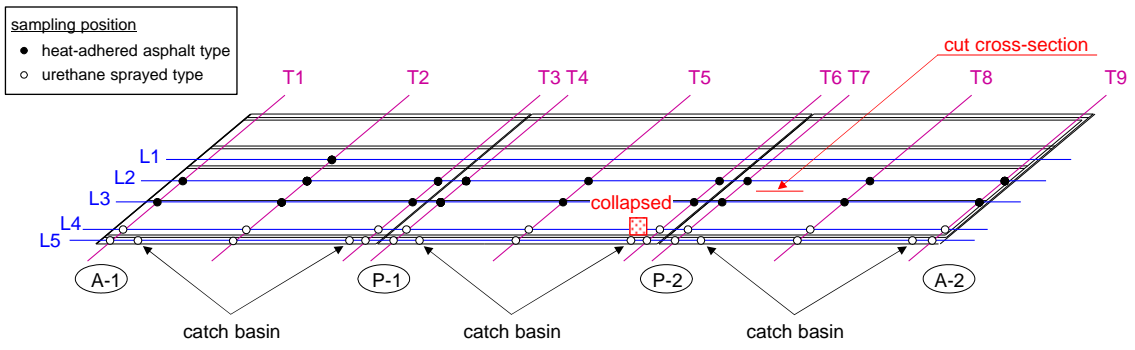


Figure 3 SAMPLING POSITION OF TENSILE ADHESIONS TEST CORES

Table 2 OUTLINE OF SAMPLING POSITION OF TEST CORES

direction	measurement line	position	Influence of wheel load	Influence of water
longitudinal	L1	near sidewalk	S	L
	L2	center of running lane	S	M
	L3	center line	S	S
	L4	just under wheel loads	L	M
	L5	near wheel guards	S	L
transverse	T1, T4, T7	near expansion joints	L	L
	T2, T5, T8	midspan	S	S
	T3, T6, T9	near expansion joints	L	L

S: small, M: middle, L: large



(a)



(b)

Figure 4 DAMAGE CONDITIONS OF WATERPROOFING LAYERS: (a) near wheel guard and expansion joint; (b) near sidewalk

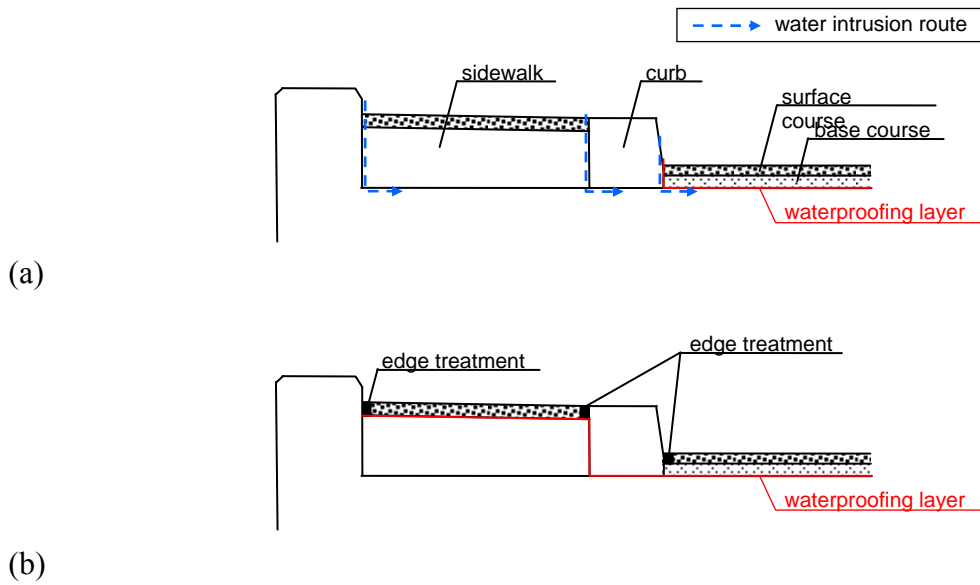


Figure 5 TREATMENT OF WATERPROOFING LAYERS NEAR CURBS: (a) current treatment; (b) desirable treatment

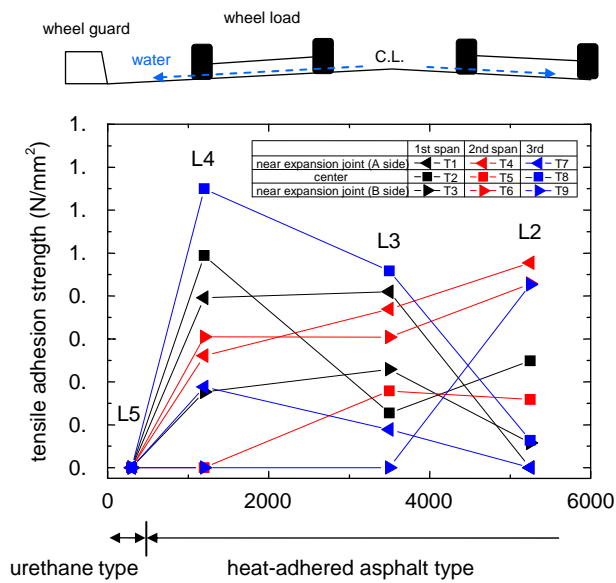


Figure 6 TENSILE ADHESION STRENGTH DISTRIBUTION IN TRANSVERSE DIRECTION

Table 3 SUMMARY OF TENSILE ADHESION TEST RESULTS

	urethane sprayed type			heat-adhered asphalt type					total
	L5*1)	L5*2)	sub total	L4	L3	L2	L1	sub total	
number of cores	6	9	15	9	11	10	1	31	46
$\sigma_t \geq 0.6 \text{ N/mm}^2$	0 (0%)	0 (0%)	0 (0%)	4 (44%)	4 (36%)	3 (30%)	0 (0%)	11 (35%)	11 (24%)
$\sigma_t < 0.6 \text{ N/mm}^2$	6 (100%)	9 (100%)	15 (100%)	5 (56%)	7 (64%)	7 (70%)	1 (100%)	20 (65%)	35 (76%)
$\sigma_t = 0 \text{ N/mm}^2$	6 (100%)	9 (100%)	15 (100%)	2 (22%)	1 (10%)	3 (30%)	0 (0%)	6 (19%)	21 (46%)

1) near catch basins, 2) near wheel guards

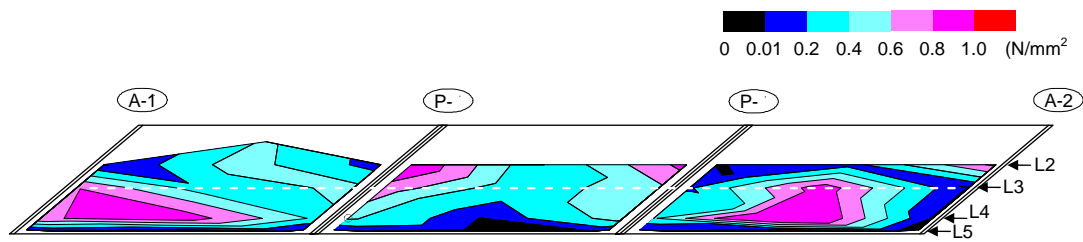


Figure 7 CONTOUR MAP OF TENSILE ADHESION STRENGTH

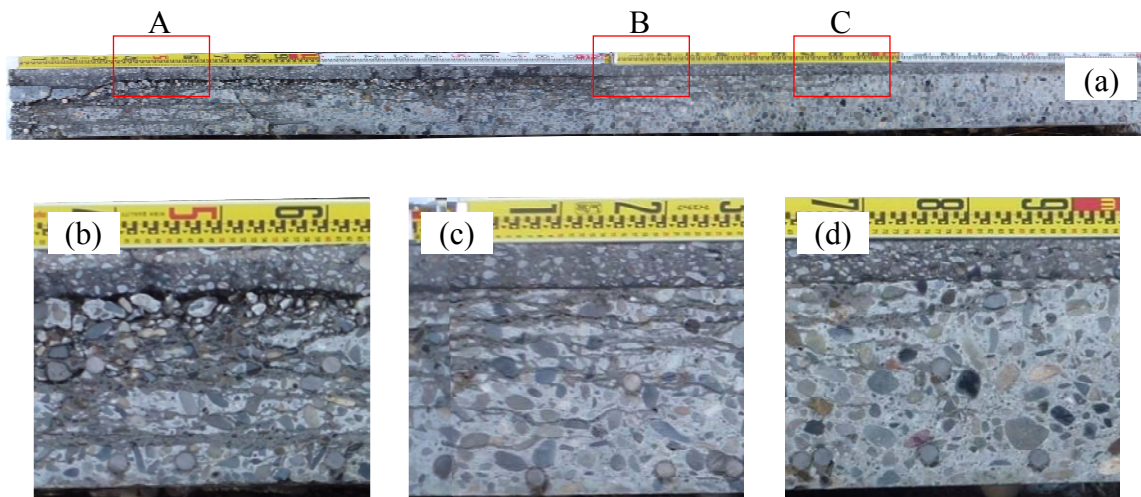


Figure 8 DAMAGE CONDITION OF RC SLAB: (a) whole view; (b)-(d) enlargement of part A, B and C, respectively

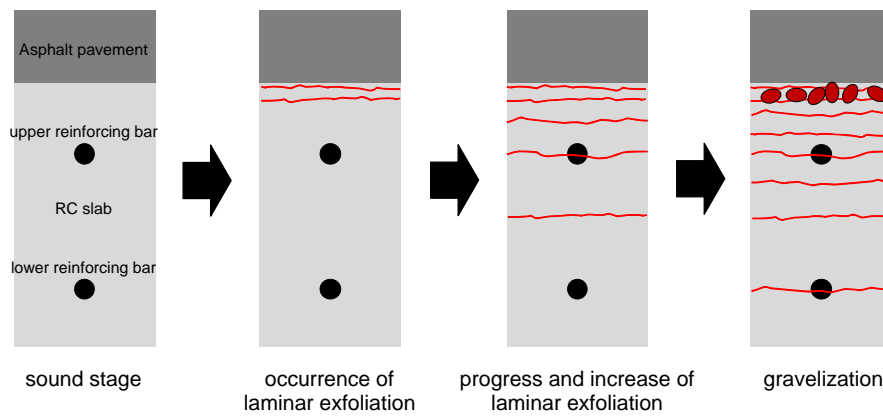


Figure 9 DETERIORATION AND DAMAGE PROCESS OF SURVEYED RC SLAB